

An R.F. Device for Precision Location of the
Beam Position Detectors in the Energy Saver

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Introduction

The requirement that the Energy Saver¹ operate in fixed-target mode with slow beam extraction and at high intensity ($\geq 2 \times 10^{13}$ protons per cycle) implies that the location of the closed orbit in the accelerator be controlled with a precision of ~ 1 mm. Transverse beam position, either horizontal or vertical, is sensed by a pair of strip line pickups^{2,3} built into an 18" long piece of beam tube which is welded onto the upstream end (proton direction) of each superconducting quadrupole as shown in Figure 1. Fabrication methods are such that a line passing midway between the pickup electrodes may be displaced as much as ± 2 mm from the magnetic centerline of the quadrupole. The striplines operate at liquid He temperature; the signal path from pickup to outside connector involves two coaxial vacuum feedthrus, a 20" piece of RG 178 cable, and three screw-on coaxial connectors. The magnetic centerline of the quad is measured under full excitation with an accuracy of ± 0.12 mm; this information is encoded on a set of 6 survey lugs attached to the outer surface of the iron yoke.

The task then is to measure the center line of the beam detector with respect to the magnetic centerline with a precision of ± 0.2 mm; the measurement must be made on 250 magnets (they come in 6 lengths, from 25" to 99") by a technician. Optical, mechanical, and electrical techniques for carrying out this procedure were considered. An R.F. device operating at 53 MHz was adopted for the following reasons: (a) it provides complete electrical checkout of the hardware at operating frequency, including the bidirectional operation of the pickup, (b) no mechanical contact with the strip lines is required, and (c) the demands of production measurements and maintenance of calibration are better matched to the skills of an average technician. In the following we describe the conceptual design, fabrication, and performance of this device.

Conceptual Design of System

Overall Design The beam position detector is a stripline directional coupler which picks up signals from the electromagnetic fields of the passing beam bunches. These signals appear at the upstream and downstream 50 Ω vacuum feedthru connectors at LHe temperature in the beam pipe location. Four jumper cables convey the signals through the cryostat vacuum to the type N connectors that are accessible to the outside world.

By stretching a wire down the quad magnetic axis, a 393 Ω coaxial transmission line is formed, running right through the detector (as would the beam). Signals at 53 MHz are launched on this wire, from a 50 Ω

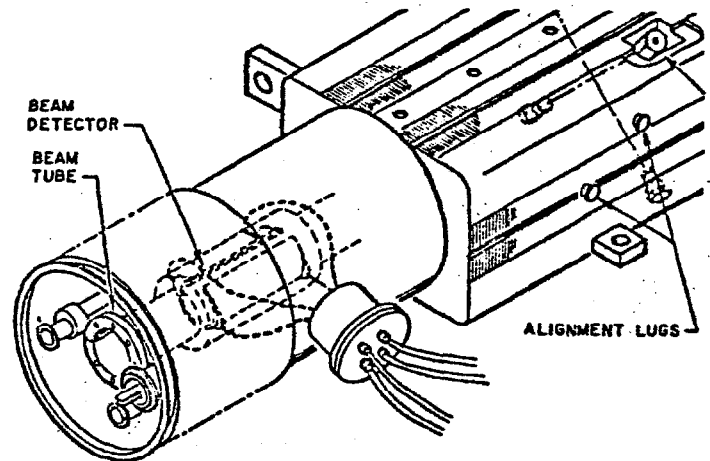


FIGURE 1
UPSTREAM END OF QUADRUPOLE SHOWING
BEAM DETECTOR ASSEMBLY

system via quarter-wave matching transformers and ferrite cavities at each end as shown in Figure 2.

The traveling electromagnetic fields on the wire are picked up by the detector plates and fed to the external N connectors. For a given RF signal amplitude on the stretched wire, the measured detector output voltages provide the means of not only calibrating the position of the detector relative to the wire, but also of making a check on the performance of connectors and jumper cables.

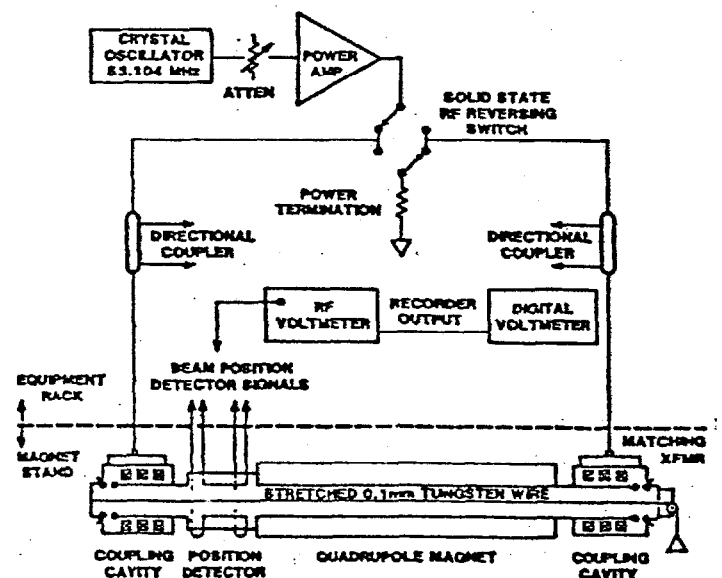


FIGURE 2
BEAM POSITION DETECTOR OFFSET
MEASURING SYSTEM

Important Parameters The critical design parameters include power level on the stretched wire, impedance-matching including the cavity shunt impedance, and signal-to-noise requirements.

a) Power Level The electrical interference at the Magnet Test Facility is appreciable, due to welders, large SCR supplies and motor starters. We therefore tested the power capability of the stretched wire with a view toward staying well above the noise level. From wire temperature measurements, we concluded that any power up to 120 watts on the wire (~200 volts and 1/2 amp) was quite safe. In day to day operation, a 2 watt power level is adequate. (The measured attenuation of the wire from D.C. to ~10 MHz is 0.026 db/ft., rising to 0.046 db/ft at 53 MHz).

b) Impedance Matching The ferrite-loaded cavities at each end of the wire have their shunt impedance in parallel with the 393 Ω wire Z_0 , and it is of interest to have the cavity shunt impedance as high as practical. We selected some ferrite cores available from previous RF systems projects, and obtained cavities of 8 K Ω shunt impedance at 53 MHz using 8 cores per cavity. The ferrite toroids, made by Toshiba of Ni-Zn ferrite M4C₂LA are 8" O.D. x 5" I.D. x 1" thick with an initial permeability of 40 and a magnetic Q of 50 at 53 MHz.

The 8 K Ω shunt impedance of the cavity appears in parallel with the 393 Ω wire Z_0 . Matching between this and the 50 Ω cable system requires some device. Quarter wave transformers are a simple solution because the system works at fixed frequency. The required transformer impedance (the geometric mean between 50 Ω and a somewhat reduced 393 Ω) is 136.8 ohms, a non-standard value. The quarter-wave transformers are described below.

c) Signal-to-noise We avoided braid cables and BNC connectors, based on our experience with their limitations. Instead, we used Andrew Heliax hard line and type N connectors for both power and signal paths. Both the stray noise pickup and the cross talk performance were adequate in situ, although we had no guarantee of this beforehand and were prepared for more stringent measures if they proved needed.

Sensitivity The sensitivity is sufficient for the required measurements. If an improvement in sensitivity were required, the RF voltmeter would be the first item to explore; its fluctuations, about 1 part in 10,000 over a second, form the first limitation one runs into in exploring possible improvements.

Mechanical Design

The R.F. Cavities are made of simple copper tubes and flat aluminum end plates. Tin plating at the contact surfaces make the compression joints reliable over the life of the instrument. The ferrite cores are supported by machined teflon strips.

A unique mechanical innovation is the shape of the quarter wave matching lines. Their 5 foot length would have been

vulnerable in the production environment. We compacted them into a spiral mounted to the top of the cavities and left only a small stub of straight length for final tuning. The spiral is a machined square groove in an aluminum plate. The size is calculated to compliment available 1/8" dia. rod in establishing the required characteristic impedance. The spiral is built up from a sequence of half circles, easily made on a computer controlled milling machine to the required 54.75" path length. The center conductor is held in position by threading through the center of closely spaced styrofoam blocks that fit tightly into the groove. The contact surfaces of the grooved plate, cover and split tuning stub line are all plated with tin to assure reliable contacts.

Stretched Wire Mounts The wire handling system does the following: positions newly threaded wires reproducibly, grounds the R.F. signal with predictable low contact resistance, and maintains the wire at a constant tension despite thermal expansion from current heating. The constant tension is maintained by a trap-door-like weight attached to one end of the tungsten wire. The wire is threaded over accurately machined vee grooved pulleys at both ends. The pulley bearings are simple cone points fitting into the pulley's axial hole and adjusted for zero play. The pulley and threaded cone points are plated with gold and lubricated with STP Oil Treatment. The weight is pivoted within a confined travel zone rather than hanging free. The opposite end's wire attachment is made like a guitar thumb screw. As the screw is turned, proper tension is reached when the weight lifts off its lower rest.

The pulleys are mounted to a horizontal and vertical slide system with micrometer adjustability. The sensitivity of the RF measurement system was verified by cranking the wire a known amount and reading the corresponding detector reading change. A table, common to both wire mounts, positions the stretched wire onto the magnetic center line via the alignment lugs (See Figure 1).

Electronic System

All electronics for the system is housed in a standard relay rack adjacent to the magnet support table. The RF power is generated and terminated in the rack and all signals are returned to the rack. Special considerations are given to insure solid, reliable electrical connections throughout the system. This is necessary to shield low level beam detector signals from noise generated in the industrial environment and from the RF power source for this system itself. Power line isolation is also included.

Figure 2 is a block diagram of the electrical system. An amplitude stabilized, crystal controlled 53.104 Mhz RF source, through a variable attenuator, provides input to an ENI 3200L amplifier. The amplifier feeds a solid state RF reversing switch controlling the direction of power flow along the stretched wire. This allows easy and reliable simulation of normal and

counter-rotating beams. Transmission paths between the switch and the cavities include directional couplers to monitor operating level and proper power flow.

Signals from the beam detector are transmitted back to the equipment rack on carefully matched and terminated cables, each of which have a voltage sampling tee installed. This way, no connections except the high impedance voltage probe itself need be disturbed during measurements. A Hewlett-Packard 8405A vector voltmeter is used to measure signal amplitudes. To eliminate probe to probe variations, only one probe of the two channel instrument is used. A digitized output is obtained by connecting a digital voltmeter to the recorder output of the 8405A.

Relative measurements of the beam detector signals to better than one percent is necessary to achieve the required detector location accuracy. Coupling from the ENI amplifier output to the beam detector outputs with the wire centered is -33db. This system was designed with the capability to run at 100 watts or greater if necessary to compete with the noisy environment. Nominal operation at about 2 watts has proved satisfactory. This provides beam detector signals to be measured in the one milliwatt range.

Procedure and System Performance

The quadrupole is placed on the table by crane and the six alignment lugs on the magnet are referenced to six alignment pads on the table by means of five adjustment screws. The RF cavities are slid into position and bolted onto the beam tube vacuum flanges at either end and the wire inserted and tensioned. With a standardized RF power flow in the proton direction, six voltmeter readings are taken: four from the two directional couplers in the transmission lines to the cavities and two from the beam detector signals. Power flow is then reversed to the anti-proton direction and six more readings taken. The two beam detector offsets for proton and anti-proton directions are then calculated, if the two offsets disagree by more than 0.005", the measurement is repeated. A 0.001" relative offset of wire and magnet is easily detected. The entire procedure is accomplished by a technician in ~1 hour. Over the past 16 months, the beam detector offsets for 275 quadrupoles have been measured with this system, it has proven to be highly reliable. A check of the geometric calibration is performed monthly using optical survey techniques. Two measurements on the same magnet separated in time by several weeks agree within ± 0.003 ". The measured distributions for the beam detector offsets for the two types of quadrupoles are given in Figure 3. The F-type magnets have a mean horizontal offset of +0.28 mm with an r.m.s. variation of 0.62 mm; the D-type magnets have a similar distribution in the vertical direction. The largest offset found was 2.5 mm.

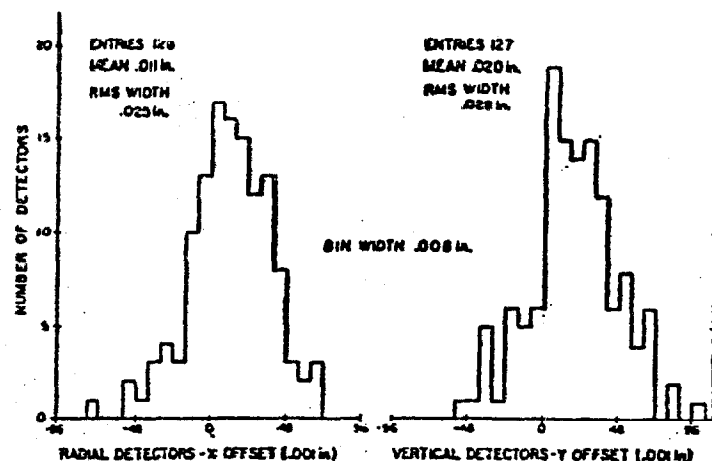


FIGURE 3
DISTRIBUTION OF MEASURED BEAM DETECTOR OFFSETS

References

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